

A new attribute sampling plan using neutrosophic statistical interval method

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Abstract

In the classical statistics, for the inspection of a final lot of the product, a decision is made either the lot has good quality or not using an acceptance sampling plan. The acceptance of sampling using the classical statistics assumes that data are determinate. In some situations, the data may imprecise and even intermediate which leads to indecision about the quality of the submitted lot of the product. In this situation, neutrosophic statistics can be applied for the lot sentencing. In this paper, a new attribute sampling plan is proposed using the neutrosophic interval method. The lot acceptance, rejection, and indeterminate probabilities are computed using the neutrosophic binomial distribution at various specified parameters such as sample size and acceptance number. The efficiency of the proposed sampling plan is also discussed. A real example is also added to explain the proposed sampling plan.

Keywords Statistics · Neutrosophic · Distribution · Lot

Introduction

To achieve the high quality of the product, an inspection of the product from raw material to the final product is an essential part of the manufacturing process. The inspection of a lot of the product through the sampling plan ensures not accepting the bad lot or rejecting a good lot of the product. For the final submitted lot of the product, the supplier is often interested to know the lot acceptance probability. In the traditional acceptance sampling plan, a random sample from a lot of the product is selected and inspected for the purpose of the lot sentencing. A lot of the product is either rejected or accepted on the basis of sample information. The decision of acceptance or rejection is made under the assumption that there is no indeterminate in the data. More details about the attribute sampling plan using the traditional/classical statistics can be seen in [1].

In practice, it may possible that sample information is incomplete, complex, imprecise and indeterminate to make a decision about the lot sentencing. In this situation, the decision about a lot of the product is not binary that is either accept

or reject a lot of the product. So, we cannot apply the crisp values to make a decision such as in classical statistics. For an example, from a lot of watches, a random sample is selected and their display type is noted. It is found that 90% watches have a proper display, 10% have no display and about 10% no evidence about the type of watches. In this case, there is some indeterminacy probability which invites to use the acceptance plan using the neutrosophic statistics.

The traditional sampling plans are applied when the experimenter or the producer is certain about the proportion parameter. So, the sampling plans having the assumption of determined value cannot be applied when there is uncertainty or indeterminacy about proportion parameter. The fuzzy sampling plans have been widely applied for the lot sentencing when there is uncertainty in the proportion parameter. Several authors contributed to designing the sampling plan using the fuzzy approach, see for example, Cheng et al. [2] proposed a fuzzy testing process to select a better process. Jamkhaneh et al. [3] studied the effect of inspection error using the single sampling plan. Sadeghpour Gildeh et al. [4] and Jamkhaneh and Gildeh [5] designed double sampling plan under the fuzzy approach. Turanoğlu et al. [6] studied the characteristic curve of the sampling plan. Jamkhaneh and Gildeh [7] proposed the fuzzy sequential sampling plan. Divya [8] worked on a single sampling plan using the Poisson distribution. Venkateh and Elango [9] designed sampling plan for fuzzy

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gamma distribution. Kahraman et al. [10] designed the single and double sampling plans under the fuzzy approach. Afshari and Gildeh [11], Afshari et al. [12, 13] designed fuzzy plans using multiple dependent state sampling. Elango et al. [14] developed the fuzzy mathematics for the single sampling plan.

Recently, the neutrosophic logic attracts the researches due to the flexibility of dealing the indeterminacy in the observations and the proportion parameter. Smarandache [15] argued that the neutrosophic logic is the generalization of the fuzzy logic. According to [16] “a new emerging tool for uncertain data processing which is known as neutrosophic sets. A neutrosophic set has the potentiality of being a general framework for uncertainty analysis in data sets”. According to [17] “The single valued neutrosophic set is a generalization of classic set, **fuzzy** set, interval valued **fuzzy** set, intuitionistic **fuzzy** set, and paraconsistent set”. According to [18] “Neutrosophic sets are powerful logics designed to facilitate understanding of indeterminate and inconsistent information; many types of incomplete or complete information can be expressed as **interval valued neutrosophic sets** (IVNSs)”. Based on the neutrosophic logic, [19] introduced the neutrosophic statistics (NS). The NS is the generalization of the classical statistics which can be applied to analyze the data under uncertainty environment. Chen et al. [20, 21] studied rock measuring problems using the neutrosophic interval method. More details about the neutrosophic application can be seen in [22–31]. Recently, [32] introduced the NS in the area of acceptance sampling plan first time. Aslam and Arif [33] designed the sudden death test using the NS. Aslam and Raza [34] proposed the plan for multiple manufacturing lines using the NS. Aslam [35] proposed the plan for the exponential distribution using the NS. More applications of the NS can be read in [36–40].

By exploring the literature and best of author knowledge, there is no work on the design of attribute acceptance sampling plan using the neutrosophic statistics. Therefore, in this paper, we will focus to design an attribute sampling plan using neutrosophic statistics. In this paper, a new attribute sampling plan is proposed using neutrosophic statistics. The operational procedure of the proposed sampling plan is given. The lot acceptance, rejection, and indeterminate probabilities are computed using the neutrosophic binomial distribution at various specified parameters such as sample size and acceptance number. We expect that the proposed sampling plan will be more adequate, effective, flexible and information than the existing sampling plan under the uncertainty environment.

Design of the proposed plan

The existing attribute sampling plan under the classical statistics provides the two possible outcomes about the submitted

lot of the product. A lot of the product is accepted if the number of failures is smaller than the specified number of failures c , otherwise, the lot of the product is rejected. In real industry, there some situations when the experimenter is uncertain either the product should be labeled as defective or good. In the case of uncertainty, the existing sampling plan can be applied for the inspection of a lot of the product. In this section, we will discuss and propose the sampling plan under the uncertainty environment.

Let X is the quality of interest, x^L and x^U are the minimum value and maximum value of the data. Suppose that $a = [x^L, x^U]$ be the required range for the sample data. The neutrosophic interval probability (NIP) based on x^L and x^U is $p = \langle [x^L, x^U], (p_{ND}, p_I, p_D) \rangle$. Note that p_{ND} , p_I and p_D denote non-defective probability belong to determine part, indeterminacy probability belong to an intermediate-defective part and falsity-probability belong to failure range of interval $p \leq [x^L, x^U], (p_{ND}, p_I, p_D)$, respectively. The total probability for the three cases satisfies $p_{ND} + p_I + p_D \geq 1$.

The proposed sampling plan using neutrosophic statistics is stated as follows

Step-1: Select a random sample of size n from a lot of the product and obtain x^L and x^U .

Step-2: Compute mean $\bar{X} = \sum_{i=1}^n X_i/n$ and standard deviation (SD) as $SD = \sqrt{\sum_{i=1}^n (X_i - \bar{X})^2/n - 1}$.

Step-3: Set $a = [x^L, x^U]$ and compute the probability of non-defective items $p_{ND} = n_{ND}/n$, the indeterminate probability $p_I = n_I/n$ and the probability of an defective item $p_D = n_D/n$, where n_{ND} , n_I and n_D is the number of values in non-failure interval $[\bar{X} - S, \bar{X} + S]$, indeterminate/uncertain interval $[\bar{X} - 3S, \bar{X} - S]; [\bar{X} + S, \bar{X} + 3S]$ and incredible/failure interval $[x^L, \bar{X} - 3S]; [\bar{X} + 3S, x^U]$, see for example [21].

Step-4: Accept a lot of the product if a number of defectives are smaller than the allowed number of defectives c , otherwise, reject the lot of the product.

The proposed sampling consists of two parameters which are the acceptance number c and sample size n . The neutrosophic operating characteristics (NOC) function of the proposed plan using neutrosophic binomial distribution (NBD) [19] is given as follows

$$L(p) = P_R + P_I + P_A; \quad p_{ND} + p_I + p_D \geq 1 \quad (1)$$

where P_R , P_I and P_A denote a lot rejection, intermediate and acceptance probabilities, respectively.

$$\begin{aligned} P_R &= \frac{n!}{c!} P(R)^c \cdot \sum_{k=0}^c \frac{P(I)^k P(F)^{n-c-k}}{k!(n-c-k)!}, \quad P_I = \\ &\sum_{z=c+1}^n \frac{n!}{z!} P(I)^z \left[\sum_{k=0}^{c-z} \frac{P(R)^k P(F)^{n-z-k}}{k!(n-z-k)!} \right] \quad \text{and} \quad P_A = \\ &\sum_{y=c+1}^n T_y = \sum_{y=c+1}^n \frac{n!}{y!} P(I)^y \cdot \left[\sum_{k=0}^{n-y} \frac{P(R)^k P(F)^{n-y-k}}{k!(n-y-k)!} \right]. \end{aligned}$$

Note here that $P(R) = p_{ND}$, $P(I) = p_I$ and $P(A) = p_D$; $p_{ND} + p_I + p_D \geq 1$.



The lot acceptance probability is the set of the lot rejection probability, indeterminate probability, and lot acceptance probability is given by

$$L(p) = \{P_R, P_I, P_A\}. \quad (2)$$

The difference between, fuzzy statistics, neutrosophic statistics and classical statistics can be seen in the following table

Fuzzy statistics	Neutrosophic statistics (NS)	Classical statistics
The fuzzy statistics is used to analyze the uncertain data	The NS is an extension of the fuzzy statistics which deals with uncertainty and indeterminacy interval. The NS consists of determined and undetermined parts	The classical statistics cannot be applied when some observations are indeterminate. It is applied when all observations are determined
The fuzzy binomial distribution is applied when the proportion parameter is fuzzy	The NS binomial distribution provide the indeterminate, the acceptance and the rejection probabilities	The classical binomial distribution only provides the acceptance and rejection probabilities

In Tables 1 and 2, the lot rejection probability, lot rejection probability, indeterminate probability, and lot acceptance probability are presented for various values of p_{ND} , p_I , p_D , and c . In Tables 1 and 2, some calculated probabilities may larger than one so the normalized vector of probabilities can be obtained for dividing each probability for their total. Similar tables can be made for any other values of specified parameters. A program is available from the author upon request. Table 1 is presented when $c = 0, 1, 2$ and $p_{ND} = 0.80$, $p_I = 0.20$, $p_D = 0.10$ and Table 2 is given when $c = 0, 1, 2$ and $p_R = 0.67$, $p_I = 0.27$ and $p_D = 0.03$. From Tables 1 and 2, we note that the fixed value of n , the lot rejection probability, indeterminate probability, and lot acceptance probability increases as c changes from 0 to 2. Furthermore, for the fixed value of c , the lot rejection probability, indeterminate probability and lot acceptance probability decrease as n increases. For example, when $c = 0$, a lot acceptance probability is 0.1632 and it is 0.8935 when $c = 2$. The indeterminate probability decreases as c changes from 0 to 2. For an example, when $c = 0$, a lot indeterminate probability is 0.6333 and it is 0.0449 when $c = 2$.

The following algorithm is used to find the probabilities about a lot of the product.

Table 1 The lot acceptance probabilities $L(p) = \{P_R, P_I, P_A\}$ when $p_{ND} = 0.80$, $p_I = 0.20$ and $p_D = 0.10$

n	$c = 0$ $\{P_R, P_I, P_A\}$	$c = 1$ $\{P_R, P_I, P_A\}$	$c = 2$ $\{P_R, P_I, P_A\}$
5	{0.2035, 0.6333, 0.1632}	{0.2543, 0.2259, 0.5197}	{0.0616, 0.0449, 0.8935}
10	{0.0414, 0.8656, 0.093}	{0.1682, 0.5668, 0.2650}	{0.1383, 0.2681, 0.5936}
15	{0.0084, 0.9507, 0.0409}	{0.0711, 0.7864, 0.1425}	{0.1261, 0.5308, 0.3430}
20	{0.0017, 0.9819, 0.0163}	{0.0246, 0.9016, 0.0737}	{0.0766, 0.7320, 0.1913}
25	{0.0003, 0.9933, 0.0063}	{0.0076, 0.9566, 0.0358}	{0.0369, 0.8584, 0.1047}
30	{0.00007, 0.9976, 0.0023}	{0.0022, 0.9814, 0.0164}	{0.0152, 0.9292, 0.0556}
35	{0.00001, 0.9991, 0.0009}	{0.0006, 0.9922, 0.0072}	{0.0057, 0.9660, 0.0283}
40	{0.000003, 0.9997, 0.0003}	{0.0001, 0.9968, 0.0031}	{0.0019, 0.9841, 0.0139}
45	{0.0000, 0.9999, 0.0001}	{0.00004, 0.9987, 0.0013}	{0.0006, 0.9928, 0.0065}
50	{0.0000, 0.99995, 0.00005}	{0.00001, 0.9995, 0.00005}	{0.0001, 0.9968, 0.0030}
55	{0.0000, 0.99998, 0.00002}	{0.000002, 0.9998, 0.0002}	{0.00006, 0.9986, 0.0013}

Table 2 The lot acceptance probabilities $L(p) = \{P_R, P_I, P_A\}$ when $p_{ND} = 0.67$, $p_I = 0.27$ and $p_D = 0.03$

n	$c = 0$ $\{P_R, P_I, P_A\}$	$c = 1$ $\{P_R, P_I, P_A\}$	$c = 2$ $\{P_R, P_I, P_A\}$
5	{0.1419, 0.8233, 0.0348}	{0.0868, 0.4572, 0.456}	{0.0081, 0.1538, 0.8380}
10	{0.0201, 0.9687, 0.0111}	{0.0442, 0.8394, 0.1164}	{0.0176, 0.5981, 0.3842}
15	{0.0029, 0.9945, 0.0026}	{0.0136, 0.9602, 0.0262}	{0.0128, 0.8607, 0.1265}
20	{0.0004, 0.9990, 0.0005}	{0.0033, 0.9909, 0.0057}	{0.0058, 0.9591, 0.0351}
25	{0.00006, 0.9998, 0.0001}	{0.0007, 0.9980, 0.0012}	{0.0020, 0.9892, 0.0088}
30	{0.0000, 0.99997, 0.00002}	{0.0001, 0.9996, 0.0003}	{0.0006, 0.9973, 0.0021}
35	{0.0000, 0.99999, 0.00004}	{0.00003, 0.9999, 0.00005}	{0.0001, 0.9994, 0.0005}
40	{0.0000, 1.0000, 0.0000}	{0.0000, 0.99998, 0.00001}	{0.00004, 0.9985, 0.0001}
45	{0.0000, 1.0000, 0.0000}	{0.0000, 1.0000, 0.0000}	{0.0000, 0.99997, 0.00002}
50	{0.0000, 1.0000, 0.0000}	{0.0000, 1.0000, 0.0000}	{0.0000, 1.0000, 0.0000}
55	{0.0000, 1.0000, 0.0000}	{0.0000, 1.0000, 0.0000}	{0.0000, 1.0000, 0.0000}

Table 3 Comparison in the lot acceptance probabilities when $p_{ND} = 0.80$, $p_I = 0.20$ and $p_D = 0.10$

n	Proposed plan $c = 0$ $\{P_R, P_I, P_A\}$	Plan under classical statistics $c = 0$ $\{P_R, P_I, P_A\}$
5	{0.2035, 0.6333, 0.1632}	0.5904
10	{0.0414, 0.8656, 0.093}	0.3486
15	{0.0084, 0.9507, 0.0409}	0.2058
20	{0.0017, 0.9819, 0.0163}	0.1215
25	{0.0003, 0.9933, 0.0063}	0.0717
30	{0.00007, 0.9976, 0.0023}	0.0423
35	{0.00001, 0.9991, 0.0009}	0.0250
40	{0.000003, 0.9997, 0.0003}	0.0147
45	{0.0000, 0.9999, 0.0001}	0.0087
50	{0.0000, 0.99995, 0.00005}	0.0051
55	{0.0000, 0.99998, 0.00002}	0.0030

1. Specify the acceptance number c and sample size n .
2. Determine p_{ND} , p_I and p_D using step-2.
3. Find $L(p) = \{P_R, P_I, P_A\}$ using Eq. (2).

Comparative study

In this section, we will compare the proposed plan designed under the neutrosophic binomial distribution with the existing sampling plan designed under the classical binomial distribution in terms of probabilities of acceptance, rejection, and indeterminate. According to [21], a method which provides the outcomes in the interval rather than the determined values under the uncertainty environment is called the most effective method. We will select the same values of all parameters for both sampling plans. We preened the probabilities in Table 3 when $p_{ND} = 0.80$, $p_I = 0.20$, $p_D = 0.10$ and $c = 0$.

From Table 3, it can be noted that the existing sampling plan under the classical statistics method provides the determined values at all specified parameters. On the other hand, the proposed plan under the neutrosophic interval method provides the probabilities in the interval. For an example, when $n = 5$, the lot acceptance probability is 0.1632, the probability of indeterminacy (i.e., neither an acceptance nor a reject) is 0.6333. It means, that when a lot of inspection with $n = 5$ and $c = 0$ is applied for the inspection of the lot, there is 63% chance that an experimenter is undecided about the lot sentencing. By comparing both sampling plans, we note that the plan under the classical statistics only has the decision of acceptance or rejection of the lot. The existing plan does not provide any information about the indeterminacy. So, the proposed sampling under the neutrosophic statistics

is more effective and adequate under the uncertainty environment and this conclusion coincides with [21].

Application of the proposed plan

In this section, we present the application of the proposed sampling plan using the color STN displays data collected from the factory. According to [41] “Color STN displays are created by adding color filters to traditional monochrome. In color STN displays, each pixel is divided into R, G and B subpixels. In this study, the membrane thickness of each pixel is the quality characteristic”. The color STN displays data of 55 values are reported in Table 3. For the given data, some statistics are shown in Table 4. From Table 4, we note that 37 items out-of 55 items belong to the non-defective group, 16 items out-of 55 belong to indeterminacy group and 2 items out-of 55 belong to failed items group (Table 5).

The proposed sampling plan for the given data is illustrated in the following steps.

Step-1: Select a random sample of size $n = 55$ and let $c = 0$ from a lot of the product and obtain $x^L = 11,589.8$ and $x^U = 11,816.7$

Step-2: Compute mean $\bar{X} = \sum_{i=1}^n X_i/n = 11,715.2$ and standard deviation (SD) as $SD = \sqrt{\sum_{i=1}^n (X_i - \bar{X})^2/n} = 49.21$.

Step-3: Set $a = [11,589.8, 11,816.7]$ and compute $p_{ND} = n_{ND}/n = 37/55 \approx 0.67$, $p_I = n_I/n = 16/55 \approx 0.29$ and $p_D = n_D/n = 2/55 \approx 0.03$. So, $p = <[x^L, x^U], (p_{ND}, p_I, p_D)> = <[11,589.8, 11,816.7], (0.67, 0.29, 0.03)$.

Step-4: The lot rejection, indeterminate, and acceptance probability is $L(p) = \{0.0000, 1.0000, 0.0000\}$. So, the lot acceptance probability for STN displays product is 0% while the lot indeterminacy is 100%. It means, that a sample of size 5 items is selected from 16 indeterminate items.

Conclusions

A new neutrosophic fuzzy sampling plan using the neutrosophic statistics is presented in this paper. The proposed plan is more flexible than the sampling plans using classical statistics. The lot acceptance probability for various acceptance numbers and sample sizes are presented. The rules to find the probability of determinate, indeterminate and acceptance of a lot of the product given and some tables are given for the practical use. The existing sampling plan under the classical statistics has only the determined probability value and becomes the special case of the proposed plan when no certainty in the sample or in the population. The comparative study shows that the proposed plan is more effective and ade-



Table 4 Distribution of color STN displays data of 55 values

n	\bar{X}	SD	$[x^L, x^U]$	n_T in $[\bar{X} - S, \bar{X} + S]$	n_L in $[\bar{X} - 3S, \bar{X} - S]$ and $[\bar{X} + S, \bar{X} + 3S]$	n_F in $[x^L, \bar{X} - 3S]$ and $[\bar{X} + 3S, x^U]$
55	11,715.2	49.21	[11,589.8, 11,816.7]	37	16	2

Table 5 Data on color STN displays

11,816.7	11,710.1	11,722.6	11,744.1	11,681.1	11,728.4
11,712.6	11,775.2	11,743.3	11,786.1	11,760.6	11,723.6
11,721.7	11,698	11,695.9	11,726.4	11,797.2	11,773.1
11,769.1	11,800.8	11,780.7	11,670.9	11,692.3	11,666.2
11,755.2	11,712.7	11,775.5	11,731.2	11,625.6	11,757.5
11,674.7	11,729.2	11,681.3	11,636.4	11,682.1	11,667.9
11,722.9	11,655.3	11,700.2	11,754.2	11,769.9	11,705.9
11,589.8	11,738.4	11,745.4	11,727.7	11,664.3	11,647.2
11,755	11,671.8	11,705.8	11,664.2	11,677	11,680.5
11,633.6					

quate than the sampling plan using classical statistics under the uncertainty environment. The proposed sampling plan can only be used when data are discrete. It is recommended that the proposed plan should apply for the inspection of lot of products under the uncertainty environment. The proposed sampling plan using the cost model can be considered as future research. The proposed plan under the time truncated life test can be considered as future research.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interests.

Data availability statement The data underlying the results presented in the study are available within the manuscript.

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